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of the writer

HURRICANES AND SHORE-LINE CHANGES IN RHODE ISLAND

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STANDING at the sea wall at Ocean Drive, Narragansett Pier, at a little before three o'clock on that afternoon of September 21, 1938, the writer was aware that a whole gale was blowing. At that time, however, at the beginning of the flood tide, no spray came over the sea wall on the drive (Fig. 7). It is difficult to realize that within so short a period as three hours such desolation and change on a shore line could be wrought by wind and wave, which covered the drive several feet deep in an hour, even with wind velocities of about a hundred miles an hour and a resulting wind pressure of 40 pounds to a square foot (Fig. 8). From Figure 3 one gets an idea of the "atmosphere" of the storm and the low visibility.

The Narragansett region is typical of the outer shore line of Rhode Island and, in fact, of southeastern New England, with rocky cliffs and, between granite headlands, long stretches of sandy bay bars and barrier beaches surmounted by sizable sand dunes knit with grasses and partly covered with a low growth of beach plum and small shrubs. The dune belts had banks from 6 to 20 feet high facing steeply seaward not far from the old high-tide line. They sloped gently inland to the outer margin of salt marshes and lagoons. From the southwestern extremity of the state at Watch Hill, barrier beaches extend eastward for 20 miles to Point Judith, shutting off large and small lagoons or salt ponds. Two of these salt ponds, Quonochontaug and Charlestown, have had permanent inlets or "breaches"; and a new breach was made in September about three miles east of Watch Hill. A series of similar barrier beaches extends eastward from southeastern Rhode Island into Massachusetts toward Buzzards Bay. The southwest end of the terminal moraine of southern Rhode Island meets the ocean at Watch Hill in a 60-foot cliff, where it was subjected to practically the maximum fury of the storm. A hooked sandspit, Napatree and Sandy Points, projects westward from Watch Hill (Figs. 5 and 6).

The low-lying shores of the upper part of the estuary of Narragansett Bay, only 6 to 25 feet above tide, are composed almost wholly of roughly stratified sand and gravel, with some cobbles and boulders,

*The writer desires to express his appreciation to Professor Alexander Forbes and Mr. Roger T. Clapp for the use of photographs; Mr. T. W. Watson, Jr., and Mr. G. E. Morgan for photographs taken in a course in aerial geomorphology at Brown University, 1936; Mr. W. O. J. Roberts for his assistance in the preparation of the maps and other material; and Mr. R. B. Sykes, Jr., for his work in a course at Brown University in collecting and correlating the meteorological data of the great gale of September 21, 1938, obtained from airports, the Coast Guard, and Weather Bureau stations; and to these, too, for their kindly responses to requests for information.

which make up the distributary Providence sand plain of glacial-fluvial origin.

It would seem that Rhode Island presents a sufficient variety of shore-line topography to be representative of the work of the sea upon a coast line during severe gales.

Besides the topographic factor, there were certain other contributing influences, which, occurring together, brought the sum total

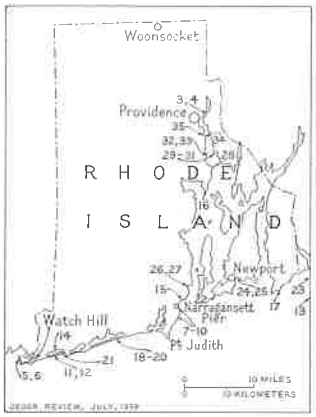

FIG. 1

FIG. 2

FIG. 1—Rhode Island. Key to location of photographs.

FIG. 2—Southern New England and Long Island showing five-minute wind velocities (miles per hour) at 3 p. m., E.S.T., with location of storm center from 3 p. m. to 6 p. m., Sept. 21, 1938. Plus signs indicate gusts of much higher velocity of less than 5-minute duration.

of the destructive and erosional effects of this storm in this region to a high level. In the first place, the phase of the moon and the autumnal equinox combined to produce one of the highest tides of the year, and the storm swell, rapidly mounting with the approach and passage of winds of the highest velocities, here coincided almost exactly with the extra-high tidal wave from ebb to flood. Moreover, as Rhode Island lay immediately to the east of the storm center, its coast line, unguarded by offshore islands between Martha's Vineyard and Fishers and Long Islands, was exposed to winds of the highest velocities; the maximum velocity of 120 miles an hour occurred just west of Watch Hill.

The cumulative and unique effect of these factors was to lift the zone of wave work some ten or twelve feet above the fairly stable level at which it had been operating for a century and to subject new and less resistant material to the erosive power of the waves. In a personal communication Rear Admiral L. O. Colbert, director of the U. S. Coast and Geodetic Survey, reports that the following figures give the

> best available values of extreme heights experienced at our primary tide stations in the area of the hurricane on September 21, 1938. The listed heights (except Boston)

were the highest on record in this office . . . Even where available, however, our automatic gauge records do not afford a satisfactory basis . . . as the gauges are not designed for this purpose . . . The heights listed are the result of . . . field examination rather than of gauge records.

Station	Feet above Mean High Water	Feet above Predicted High Water	Station	Feet above Mean High Water	Feet above Predicted High Water
Stratford, Conn.	5.6	4.6	Providence, R. I.	13.0	12.3
New London, Conn.	8.6	8.1	Woods Hole, Mass.	8.0	7.6
Newport, R. I.	10.4	9.7	Boston, Mass.	1.9	0.7

The results of erosion showed less on hardpan and rocky cliffs, except where made up of fissile shales, than on unconsolidated materials. Although the soil cover was stripped down to bedrock several feet inland from the cliff edge, as at Newport, the attack, though furious, was not long sustained, and the effects were not marked. Mechanical and chemical weathering may be a more important factor in the recession of rocky coasts than has hitherto been deemed possible. In the lower latitudes in which hurricanes normally occur they move one-quarter to one-fifth as rapidly, with higher average wind velocities. Hence the coastal attack there is much more severe and prolonged; for, instead of three to four hours, wave work may continue for a day or more.

The transporting power of the waves is indicated by the distance to which even large boulders were carried inland on low-lying shores, as at Newport (Fig. 22). Beach cobbles were thrown over a 9-foot scarp and covered a lawn for a hundred yards inland, and fine shingle was carried an equal distance up and over a 20-foot cliff by wind and spray.

The high morainal cliff at Watch Hill lost about 35 feet; the 15-foot cliffs of glacial debris, Sakonnet, receded 25 to 30 feet (Fig. 17); No Mans Land is reported to have lost 25 feet and Cuttyhunk Island about the same; the 100-foot cliff at Block Island retreated about 30 feet; and the Warwick Point lighthouse, on a 20-foot cliff *up* Narragansett Bay, was nearly undermined by a 38-foot recession (Fig. 16).

Ordinary barriers of bulkheads, breakwaters, and jetties were first battered by storm waves and rising waters, then weakened and buried by maximum high water, and finally undermined and destroyed by outrushing tides and the still furious waves at a lower level (Figs. 28, 30, 31, 34, and 35). It may be noted that the erosion level is determined by the height of resistant bulkheads.

The low-lying sand beaches of the South Shore, dotted with large and small cottages on, in, and in the lee of the dune belt, and the crescentic bay-bar bathing beaches of Newport, the Pier, and The Bonnet show the greatest topographic changes and suffered the greatest property damage and the greatest loss of life. Under the storm waves miles of dunes 6 to 20 feet high and about a hundred feet thick at the base were virtually "dissolved" and were swept inland to make a much wider new upper beach. The new profile shows a much-thickened slope inland from an altitude of 4–5 feet above high tide to the new margin of the greatly, though irregularly, reduced salt ponds (Figs. 18 and 19). An early stage in this erosional process can be observed in the storm undercutting of dunes in 1931 (Fig. 15). Here and there fragments of the dunes were left, as at Misquamicut, R. I., and Horse Neck Beach, Westport, Mass. (Figs. 21 and 23). Where natural bedrock gave a secure and slightly higher foundation, as at Quonochontaug, or heavy masonry served the same purpose, as at Misquamicut, structures remained as isles of safety amidst the wreckage.

Only two breaches in the beaches remain, one near Misquamicut (Fig. 14) and the other beyond Napatree Point. The latter will probably be kept open; but the former is being filled, to hasten nature's inevitable process. Quicks Hole, Nashawena Island, of the Elizabeth Islands group, Buzzards Bay, Massachusetts, shows the breaching of the bar by gale waves and its filling by December 13 at a lower level and farther seaward than the breach (Fig. 13).

Professor Alexander Forbes of the Harvard Medical School shows by views and observations from the air that four days after the hurricane the east end of Cuttyhunk Island was still cut off from the rest of the island just west of the Coast Guard Station by a breach in the bar but that by December 13 the breach had healed itself. Nature followed the same method at the ruptured sandspit off South Wareham, Mass., and probably at the south beach of Menemsha Pond east of Gay Head.

Just as the natural healing processes tend to close the gale-made inlets, so dune building, which had been in progress since the great gale of 1815 and the minor one of 1869, is developing rapidly on the Charlestown beach (Figs. 19 and 20). With a three times wider sand area for westerly and northwesterly winds to draw from, dunes should build somewhat more rapidly than before the storm.

The new high beach profile shows a tendency toward a gentler slope with possibly a slight convexity in places (Figs. 32 and 33). Beach material has changed in character and position. Directly after the gale it was reported that coarse or stony upper parts of beaches were covered with hard-packed sand; but unfortunately wave and rain only washed it lower down on the beach. In general, the change in the ordinary beach was slight, and that toward betterment of the high beach.

The bay-bar bathing beaches at Newport, Bailey's, Viking, Easton (Town), Second, and Third, and also the beaches at Narragansett Pier

FIG. 3

FIG. 4

FIG. 5

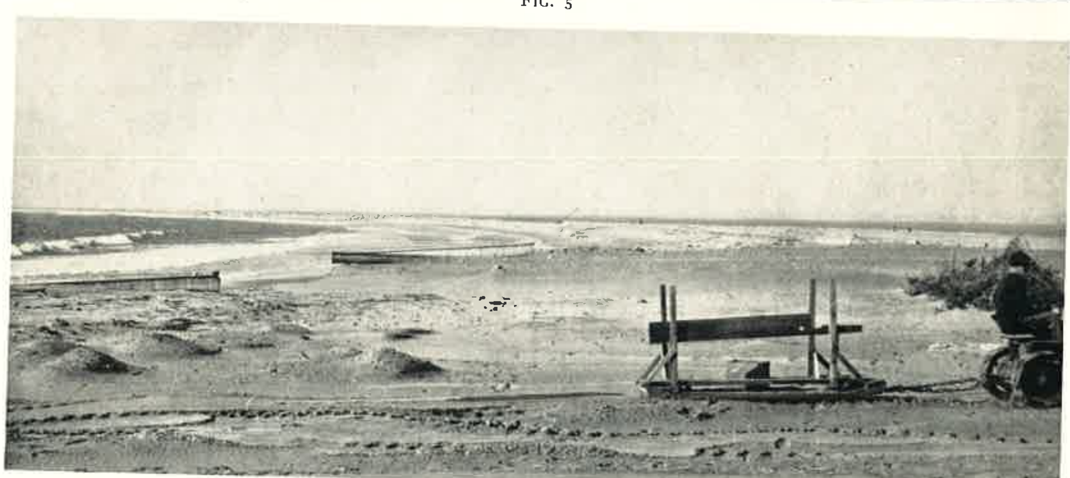

FIG. 6

FIG. 3—Brown University boat-clubhouse, Seekonk River, Providence, during height of gale, 5:45 p. m., Sept. 21, 1938.
FIG. 4—Brown University boat-clubhouse the morning after the gale, Sept. 22. Compare the foliage in Figure 3.
FIG. 5—Napatree Point and Watch Hill, 1936. Thirty-nine cottages on the low sandbar disappeared. This bar was breached but filled later; but the breach in the nearer bar still remains open. (Photograph by W. and M.)
FIG. 6—Watch Hill to Napatree Point, Dec. 4, 1938. Forty cottages were grouped here; useless groins still remain at the bathing beach.

m., Sept. 21, 1938.
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. This bar was breached

groins still remain at the

FIG. 7

FIG. 8

FIG. 9

FIG. 10

FIG. 7—Narragansett Pier Ocean Drive and retaining wall and jetty, 1911.

FIG. 8—Narragansett Pier Ocean Drive. Wreckage of wall and two-thirds of drive and transportation of two-ton fragments. Dec. 4, 1938.

FIG. 9—Narragansett Pier Beach showing character and extent of storm-wave destruction. Dec. 4, 1938. Compare with Figure 10.

FIG. 10—Narragansett Pier Beach with bathing pavilion and houses, 1925.

FIG. 11—Aerial view east over Winnepaug or Brightman Pond and beach, taken by Dr. Alexander Forbes four days after the hurricane, illustrating the erratic widening of beach area inland, the irregular line of flotsam and jetsam and the stranding of wave-carried cottages. Compare with Figure 12. The gale-made breach at the arrow still remains open, as is seen in Figure 14.

FIG. 12 (above)—Aerial view east over Winnepaug or Brightman Pond and beach, 1936, showing general plan of beach occupation: outward line of dunes with perched and nestling cottages; protected road with cottages either side between dunes and lagoons. (Photograph by W. and M.)

FIG. 13 (below)—Aerial view of Quick's Hole, Nashawena Island. Gale breach in bar filled by December 13, 1938. (Photograph by Dr. Alexander Forbes.)

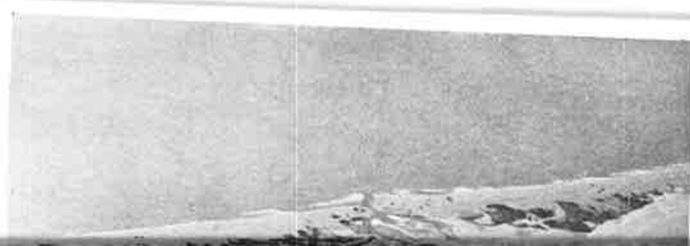

FIG. 11—Aerial view east over Winnepaug or Brightman Pond and beach, taken by Dr. Alexander Forbes four days after the hurricane, illustrating the erratic widening of beach area inland, the irregular line of flotsam and jetsam and the stranding of wave-carried cottages. Compare with Figure 12. The gale-made breach at the arrow still remains open, as is seen in Figure 14.

FIG. 12 (above)—Aerial view east over Winnepaug or Brightman Pond and beach, 1936, showing general plan of beach occupation: outward line of dunes with perched and nestling cottages; protected road with cottages either side between dunes and lagoons. (Photograph by W. and M.)

FIG. 13 (below)—Aerial view of Quick's Hole, Nashawena Island. Gale breach in bar filled by December 13, 1938. (Photograph by Dr. Alexander Forbes.)

FIG. 14 (above)—Breach in Atlantic Beach and Winnepaug Pond, west of Noyes Point; one of the two gale breaches still remaining open. The beach, clean-swept of structures and debris, shows the erratic widening from flattening of sand dunes. Jan. 26, 1939. Compare Figures 11 and 12. (Photograph by Dr. Alexander Forbes.)

FIG. 15 (below)—Gale erosion of footing of Narragansett sand dunes by some six feet, 1931. These dunes were practically obliterated in the 1938 hurricane.

FIG. 16 (above)—Warwick Point Light, nearly undermined by 38-foot erosion of glacial debris and hard pan on a bench of graphitic shale flush with the five-foot bulkhead.

FIG. 17 (below)—Warren Point, Sakonnet. Fifteen-foot cliffs of glacial debris cut back by storm waves 30 feet from zone of lighter-colored shingle.

Fig. 18

Fig. 19

Fig. 20

Fig. 21

Fig. 18 (pp. 424 and 425)—Charlestown Beach, R. I. Ninety-odd cottages disappeared with the dunes just in front of the road and line of poles, where the storm swell swept all into the lagoon. Concrete garage floors and bent galvanized water and drain pipes are all that remain to show the site of the cottages. April 5, 1939.

Fig. 19—Buried road at Charlestown Beach excavated through sand wash on inner side of former dunes. The distant figures are not far from high-tide mark. Oct. 16, 1938.

Fig. 20—The road in Figure 19 was nearly filled in seven weeks by drifting sand. Dec. 7, 1938. Dune modeling evident.

Fig. 21—Misquamicut Beach bridge (repaired), breached dunes, and stranded cottage near outlet of Brightman or Winnepaug Pond. Dec. 4, 1938.

, 20

unes just in front of the road
nt galvanized water and drain

er dunes. The distant figures

ıne modeling evident.
t of Brightman or Winnepaug

FIG. 18 (contd.)

FIG. 22

FIG. 23

FIG. 18 (contd.)—See opposite page for legend. The right and left halves of the panorama overlap.

FIG. 22—Ocean drive at Brenton's Reef Point, Newport. Wave-borne boulders carried in nearly 100 yards, 12 feet above mean high water, simulating an elevated beach. Nov. 4, 1938.

FIG. 23—Horse Neck Beach, Westport, Mass. The belt of dunes protecting the line of poles was destroyed and the road covered with dune and beach material to a depth of several feet. Erosion continued inland 125 feet into the major dune belt. Oct. 26, 1938.

FIG. 24

FIG. 25

FIG. 24—Newport Town (Easton's) Beach and amusement structures with lagoon in back and Easton's Point and Second Beach in distance in 1936. The famous "Cliff Walk" shows in lower right. (Photograph by W. and M.)

FIG. 25—Newport Town (Easton's) Beach. Total destruction of all buildings save one concrete boxlike affair. Partial damage of road and wall with road cleared of three feet of debris. Waves swept salt water into city reservoir six feet above lagoon. Nov. 2, 1938.

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aph by W. and M.)
crete boxlike affair. Partial
into city reservoir six feet

FIG. 26

FIG. 27

FIG. 26—Westquage Beach (Bonnet Shores). Bay bar with bathing beach structures and sand-dune belt 20 feet high above high tide, 1936. (Photograph by W. and M.)

FIG. 27—Westquage Beach (Bonnet Shores), from the west end showing distribution of dunes inland with entire destruction of buildings. Oct. 14, 1938.

FIG. 28

FIG 29

FIG. 30

FIG. 31

FIG. 28 (pp. 428 and 429)—Conimicut Point, Shawomet, R. I. Panorama illustrating damage to low jetties and bulkheads, erosion of soil and obliteration of about 100 cottages formerly on this low narrow sandspit four to six feet above tide. All the area shown in the panorama was covered with from 6 to 8 feet of storm-driven water. Nov. 20, 1938.

FIG. 29—Bullocks Point, south of Riverside, R. I., 1936. Of the twelve south-facing cottages all but two (Fig. 31) disappeared. On the west (left) shore many cottages were partial losses by the undercutting of the fifteen-foot sand-plain cliffs in spite of supposedly protective 5-foot and 10-foot bulkheads. (Photograph by W. and M.)

FIG. 30—Bullocks Point cottages and bulkheads, 1936.

FIG. 31—Bullocks Point, Oct. 7. 1938.

FIG. 28 (contd.)

FIG. 32

FIG. 33

FIG. 34

FIG. 35

FIG. 28 (contd.)—See opposite page for legend.

FIG. 32—Gaspee Point (south), R. I. Beach profile at low tide before gale erosion, 1930.

FIG. 33—New upper beach profile at Gaspee Point. Note slight convexity of upper beach in erratic gale erosion of 15-foot cliffs of sand-plain material.

FIG. 34—South of Rhode Island Yacht Club, Pawtuxet, showing erosion above bulkheads at two levels. For protection bulkheads must be as high as waves.

FIG. 35—North of Rhode Island Yacht Club, Pawtuxet. Cliff erosion in sand and gravel sand plain, inland from trees and low 4-foot retaining walls by undercutting and slumping. Original slope may be seen in distance. April, 1939.

and Bonnet Shores, all had a large number of pavilions, houses, and amusement structures built on them. These low-lying beaches were swept practically clean of buildings. In places erosion was concentrated at the center, the west or the east end of the beach according to the direction of the wave action (Figs. 9, 10, 24, 25, 26, and 27).

Conclusions

From the foregoing observations on wave erosion and deposition under abnormal storm conditions certain conclusions appear. In the first place, it must be emphasized that wave erosion and tidal scour proceed very swiftly in a higher, weaker zone not usually affected by ordinary gales. In this zone recession of the coast line at the higher level probably amounted to as much as 25 to 40 feet—accomplished in three to four hours. Coastal retreat during a great storm in which all conditions or factors coincide to produce the maximum effect may be far greater than that effected in a century of ordinary wave work. From studies of the slight amount of storm-wave erosion of rocky cliffs, it might be suggested that weathering agents may be more responsible for cliff recession than even high waves.

Moreover, the origin of high-level erosion "nicks" and apparent boulder beaches must be considered in evaluating evidence in small amounts of problematical land uplift; for identical products may result from either land uplift or elevation of the sea by a storm swell. The term "splash benches" might well be assigned to longer-continued erosion by the storm swell of the more frequent hurricanes of the tropics.

Again, barrier beaches are breached now and then during severe winter gales. Where the body of enclosed water is not large enough to afford sufficient tidal scour to keep the breach open, its natural closure is only a matter of time.

In addition, it may be said that the dunes have been the result of more than a century's accumulation, for the salt-water lagoons showed very little curtailment up to the time of this last storm. The dunes will once more begin their cycle of growth and will continue until another great gale carries them into the decreasing lagoons.

Some engineering lessons have been learned: more massive and solid and deeper foundations for shore structures are imperatively necessary in exposed places; protective devices such as bulkheads must be higher and stronger even in upper Narragansett Bay to serve their purpose; and certain provisions must be made to protect life on the beaches in late August and September.